Positive and negative sequence currents optimization to improve voltages during unbalanced faults

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***Abstract*—Grid faults constitute a series of unfortunate events that compromise power systems. With the increasing integration of renewables and their associated power electronics converters, the injected currents are controllable, but at the same time, they have to be limited so as not to damage the semiconductors. This poses the challenge to determine the combination of currents that improves the most the voltages at the point of common coupling. In this paper, such an issue is approached from an optimization perspective. Solving the optimization problem allows comparing its solutions with respect to the ones obtained by following the grid code control laws. Two fundamental scenarios are presented: one with a single converter, and another with two converters. Several parameters are varied for all kinds of faults to spot the changes on the currents, such as the severity of the fault, the distance of a hypothetical submarine cable, and the resistive/inductive ratio of the impedances. Overall the results indicate that injecting only reactive power is not always the preferable choice. While grid codes are not optimal, they can be regarded as near-optimal decision rules.**

***Index Terms*—Voltage imbalance, Unbalanced fault, Grid code, VSC current saturation, Positive sequence voltage maximization, Negative sequence voltage minimization**

I. Introduction

THE rise in renewable energies has carried along with it the inclusion of Voltage Source Converters (VSC) as a means of coupling energetic resources to the grid while providing controllability [1]–[3]. Adopting such power electronics equipment has induced a progressive shrinkage on synchronous generators' influence in power systems. Even though synchronous generators suffer an increase in current during faults, which causes protective relays to trigger, the issue is much more prominent in power-electronics-based grids as current spikes are likely to damage the Isolated-Gate Bipolar Transistors (IGBT) found in VSC [4]. Indeed, current (and also voltage) limitations cause VSC to behave differently. They reach what is called a saturated state. Many equilibrium points may arise as a result of that, especially in grids formed by multiple converters operating in critical conditions. The solution to such systems is also likely to become an arduous task to compute, as saturation states are defined by non-linear equations, or in more detail, by piecewise functions.

Not only do currents have to be constrained to not exceed the limitations, but they also have to collaborate on improving the voltages. This becomes visible when looking at the requirements imposed by Transmission System Operators (TSO) in its grid codes [5], [6]. Although this was not the case years ago, when wind power represented a small percentage of the electricity mix, nowadays wind power plants have to control active and reactive power so as to offer frequency support and voltage support respectively [7]. Besides, they have to transiently support the faults. The latter aspect is often referred to as low voltage ride through (LVRT) [8], [9]. The traditional approach to raise the voltage at the point of common coupling is to inject reactive power proportionally to the severity of the fault [7], [10]. During the analysis of faults, it is often the case that voltages are decomposed into positive, negative and zero sequence values. By doing so, the study of the fault is expected to be simplified, and in addition to that, some intuition can be build from inspecting the positive and negative sequence voltages. A concerning unbalanced fault is such that substantially decreases the positive sequence voltage with respect to the nominal voltage while the negative sequence voltage increases. Both sequences have to be thoroughly controlled, as discussed in [10], [11].

Nevertheless, grid codes only specify reactive power injection during faults [12], [13]. This makes sense considering that transmission power lines are mainly inductive. When positive sequence reactive currents take negative values, significant voltage drops appear, which aids in increasing the voltage at the point of common coupling. In case negative sequence reactive currents take positive values, the negative sequence voltage diminishes. This strategy is likely to become suboptimal since transmission lines are not purely inductive. The influence of impedances is covered in [11], where the authors express the currents to inject as a function of the voltage and the impedances. A recursive relation between the voltage and the current is found. This invalidates the possibility of working with a closed-form expression from where to compute the optimal currents solution. Expressions of the same nature are proposed in [14], where instead of attempting to solve the optimization problem, a control parameter is introduced. This takes various values, but no analysis is carried out to determine the optimal choice. Reference [15] proposes a maximum allowed support (MAS) control scheme that is said to provide the maximum voltage support and simultaneously satisfy the constraints. The study does not explicitly indicate how the current is distributed among the real and the imaginary positive and negative sequence components, and variations in input parameters are rather limited. Another voltage support scheme is presented in [16], where the injected currents do not depend neither on the active power nor the filter resistance. In addition, positive and negative sequence grid voltage values are imposed, which further facilitates the obtention of the steady-state current values.

Consequently, the problem has to be presented as an optimization problem, where the objective is to maximize the positive sequence voltage and/or minimize the negative sequence voltage, all this constrained to not surpass the current

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limitations. This paper solves precisely the above-mentioned optimization problem. Two other control rules are implemented. One focuses on solving the optimization problem but in addition to the other constraints, it is restricted to only injecting reactive power. The third control rule follows the implementation of grid code specifications with its characteristic droop profile. These three options are tested for both balanced and unbalanced faults, where this last category includes the line to ground, the line to line and the double line to ground faults. First, a basic system with a single converter is studied. Then, the analysis is repeated for a system with two converters in order to identify their interaction in saturated states.

The structure of the paper is as follows. Section II formulates the optimization problem and details the methodology employed. Section III presents the results together with the corresponding discussion for a single converter case. Section IV analyzes similar situations for a basic power system with two converters. Finally, Section V concludes this work.

II. Problem formulation

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III. Single converter case study

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IV. Two converter case study

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V. Conclusion

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Acknowledgment

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References

[1] M. Imhof and G. Andersson, "Power system stability control using voltage source converter based hvdc in power systems with a high penetration of renewables," in *2014 Power Systems Computation Conference*. IEEE, 2014, pp. 1–7.

[2] S. Eren, A. Bakhshai, and P. Jain, "Control of three-phase voltage source inverter for renewable energy applications," in *2011 IEEE 33rd International Telecommunications Energy Conference (INTELEC)*. IEEE, 2011, pp. 1–4.

[3] F. Blaabjerg, Y. Yang, K. Ma, and X. Wang, "Power electronics-the key technology for renewable energy system integration," in *2015 International Conference on Renewable Energy Research and Applications (ICRERA)*. IEEE, 2015, pp. 1618–1626.

[4] A. Abdou, A. Abu-Siada, and H. Pota, "Improving the low voltage ride through of doubly fed induction generator during intermittent voltage source converter faults," *Journal of Renewable and Sustainable Energy*, vol. 5, no. 4, p. 043110, 2013.

[5] I. Erlich, W. Winter, and A. Dittrich, "Advanced grid requirements for the integration of wind turbines into the german transmission system," in *2006 IEEE Power Engineering Society General Meeting*. IEEE, 2006, pp. 7–pp.

[6] X. Zhang, Z. Wu, M. Hu, X. Li, and G. Lv, "Coordinated control strategies of vsc-hvdc-based wind power systems for low voltage ride through," *energies*, vol. 8, no. 7, pp. 7224–7242, 2015.

[7] M. Mohseni and S. M. Islam, "Review of international grid codes for wind power integration: Diversity, technology and a case for global standard," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 6, pp. 3876–3890, 2012.

[8] M. Tsili and S. Papathanassiou, "A review of grid code technical requirements for wind farms," *IET Renewable power generation*, vol. 3, no. 3, pp. 308–332, 2009.

[9] J. Conroy and R. Watson, "Low-voltage ride-through of a full converter wind turbine with permanent magnet generator," *IET Renewable power generation*, vol. 1, no. 3, pp. 182–189, 2007.

[10] A. Haddadi, I. Kocar, J. Mahseredjian, U. Karaagac, and E. Farantatos, "Negative sequence quantities-based protection under inverter-based resources challenges and impact of the german grid code," *Electric Power Systems Research*, vol. 188, p. 106573, 2020.

[11] A. Camacho, M. Castilla, J. Miret, L. G. de Vicuña, and R. Guzman, "Positive and negative sequence control strategies to maximize the voltage support in resistive–inductive grids during grid faults," *IEEE Transactions on Power Electronics*, vol. 33, no. 6, pp. 5362–5373, 2017.

[12] R. E. de España. (2016) Información sobre implementación de códigos de red de conexión. textos de los códigos de red de conexió europeos. reglamento 2016/631. [Online]. Available: https://www.esios.ree.es/es/pagina/codigos-red-conexion

[13] A. G. Paspatis and G. C. Konstantopoulos, "Voltage support under grid faults with inherent current limitation for three-phase droop-controlled inverters," *Energies*, vol. 12, no. 6, p. 997, 2019.

[14] A. Camacho, M. Castilla, J. Miret, J. C. Vasquez, and E. Alarcon-Gallo, "Flexible voltage support control for three-phase distributed generation inverters under grid fault," *IEEE transactions on industrial electronics*, vol. 60, no. 4, pp. 1429–1441, 2012.

[15] M. M. Shabestary and Y. A.-R. I. Mohamed, "An analytical method to obtain maximum allowable grid support by using grid-connected converters," *IEEE Transactions on Sustainable Energy*, vol. 7, no. 4, pp. 1558–1571, 2016.

[16] Z. Dai, H. Lin, H. Yin, and Y. Qiu, "A novel method for voltage support control under unbalanced grid faults and grid harmonic voltage disturbances," *IET power Electronics*, vol. 8, no. 8, pp. 1377–1385, 2015.